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A HISTORICAL SUPERNOVA'S LOWER LIMIT TO THE GALACTIC STELLAR-COLLAPSE RATE

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Abstract

This paper re-investigates the rate of galactic supernova given by historical supernova. The influence of various selection effects, including galactic extinction, and the type and scale height of supernova, are considered in detail. A lower limit to the rate of stellar collapse in the galaxy is set at > 1/20 yr . If the recently proposed six candidates are included, the lower limit becomes > 1/12 yr . These lower limits do not greatly differ from the rates given by the heavy element content and the stellar formation of the galaxy. This implies that the variation and the activity in galactic evolution may not be very strong.

1. The rate of the gravitational collapse of stars is one of the keys to the study of galactic evolution. This rate has been indirectely estimated from the birth rate of radio pulsars[1], stellar distributions and evolutionary lifetimes[2], and galactic chemical evolution[3]. Recently, a more direct estimate has been derived from a search for bursts of low-energy neutrino[4], which are the immediate result of stellar core collapse. The negative result of no such brusts to be observed in a period of 5.6 years sets an upper limit to the galactic stellar-collapse rate at about < 1/1.1 yr^{-1} . As we know, the only positively observed result, which is directly related to galactic stellar collapse of the galaxy, is the historical supernova. Therefore, the rate of galactic stellar collapse can also be estimated from the data of historical supernovae[5]. These estimates are very uncertain due to the assumptions and approximations needed for an incomplete sample as that of historical supernova. Nevertheless, such an incomplete but positive sample can be used to find a confident lower limit to the rate of the galactic stellar collapses. In this paper we re-investigate the influence of various selection effects on the determination of the stellar collapse rate by means of historical supernova. In particular, we focus on finding a lower limit to the rate.

Up to now, at least 8 "guest stars" in the historical literature covering the period of the last two thousand years have been identified as supernova[5]. Table 1 lists these historical supernovae and relevant data, including supernova remnant (SNR), distance from galactic center R, height from the galactic disk z.

It is very difficult to estimate the completeness of the sample provided by historical records, especially, since almost all records on historical supernova are found in ancient Chinese literatures. Considering that there were frequent social upheavals in Chinese history, how can we be sure that the record is complete enough to do statistics ?

Table 1. Historical supernova

SN	SNR	R (Kpc)	z (Kpc)	type
AD185	G315.4-2.3	2.5	80	?
AD386	G11.2-0.3 ?	5	30	?
AD393	G348.5+0.1 ?	10.2		?
AD1006	G327.6+14.5	2.4	600	?
AD1054	G184.6-5.8	2.0	200	2
AD1181	G130.7+3.1	8.0	430	2
AD1571	G120.1+1.4	6.0	150	1
AD1604	G4.5+6.8	10	1200	1

In fact, however, there seems to be some grounds for believing that the sample of the historical supernova is complete. Indeed, it has already been shown that the number of sunspots recorded in Chinese historical literature seems not to be strongly correlated with the events of upheaval. This is, the historical record of sunspots appears homogeneous. This is probably because in ancient time, during periods of upheaval, the authorities have paid more attention to the cataclysmic phenomena in the sky. The more confusing the situation was, the more astrology the emperor needed. Since supernova is the most abnormal phenomenon visible to the naked eye, the historical records on supernovae might also be homogeneous or at least as good as those of sunspots.

Nevertheless, the sample of historical supernova is incomplete. For instance, SNR Cas A is located within a distance, at which a supernova should be visible to the naked eye. No historical record, however, can be identified as the supernova of Cas A. More recently, Li proposed[6] that, in addition to the 8 supernova in table 1, there are six other records of "guest stars", which are most likely to be supernovae. This means that the identification of supernova may also be incomplete due to the indistinctness in the historical literature. Therefore, the sample of historical supernovae is not available for determining the rate of galactic stellar collapse. On the other hand, in determining a lower limit of the rate, we do not need a complete sample, but only confidence in the identification of supernova. Therefore, it is rather safe to use the 8 identified records as a lower limit of the number of visible-to-the-naked-eye supernovae in the whole A.D. period.

2. The rate of galactic supernova D is given by

$$D = D_1 + D_2 \ , \tag{1}$$

where D_1 and D_2 are, respectively, the rates of type 1 and 2 supernovae. Since only type 2 supernovae come from stellar collapse, D_2 describes the rate of the galactic stellar collapse. D_i can be found from historical supernovae by

$$D_i = n_i \ / \ t\eta f_i \ , \tag{2}$$

where $i = 1$ and 2; n_i is the number of type i supernova recorded in the historical duration t; and f is the fraction of supernovae lying in a range of galactic disk, within which supernova are visible to the naked eye. η is the factor of completeness of the sample.

The maximum distance r_{imax}, within which the type i supernova are visible to the naked eye, is given by the solution of the following equation

$$5 \log r_i + Ar_i = m_i - M_i + 5 , \qquad (3)$$

where M_i is the absolute magnitude of type i supernova; m_i is the limit of apparent magnitude of the sample; and A is the coefficient of extinction in galactic disk. A depends on the height of supernova as follows

$$A = A_o [1 - \exp (-z/H_1)] / (z/H_1) , \qquad (4)$$

where H_1 = 125 pc is the scale height of the gas component of the galactic disk; and the values of A_o , depending on the direction of objects, is in the range of 2 ~ 8 kpc . From eqs.(3) and (4), one can find the maximum distance r_{imax} as a function of z. $r < r_{imax}$ defines a region, within which type i supernova is visible to the naked eyes.

The number of supernovae lying within the visible region is

$$N_i = N_o \frac{5}{6} \int \pi [r^2_{imax}(z) - z^2] e^{-(z/H_2)} dz , \qquad (5)$$

where N_o and H_2 are the number density and scale height of supernovae, respectively. The integral in eq.(5) is taken over the range given by $z < r_{imax}(z)$ and $r_{imax}(z) < R$, R being the radius of the galaxy. The correction factor 5/6 in eq.(5) is due to the fact that, if the sun lies nearly in the line of sight of an observer to a supernova, then the supernova is invisible.

Therefore, one finds finally

$$f_i = N_i \ / \ N_T \ , \tag{6}$$

in which the total number of supernovae in the galaxy, N_T, can be estimated as

$$N_T = N_o \int \pi R^2 \ e^{-(z/H_2)} \ dz \ , \tag{7}$$

3. In order to find a lower limit of D, we should take η to be equal to its maximum, i.e. $\eta = 1$; and A_o to its minimum, i.e. $A_o = 2.0$ Kpc. Since all supernovae in table 1 were visible for a duration of equal to or longer than six months, the apparent magnitude of all supernovae at their maximum brightness must be equal to or less than $m = 3$. Therefore, we have the limit of apparent magnitudes in eq.(3) $m_1 = m_2 = 3$.

The absolute magnitude of supernova is taken to be $M_1 = -19$ for type 1, and $M_2 = -17$ for type 2. The lower absolute magnitude of SN 1987A implies that some supernovae in the galaxy are dim. This leads to more uncertainty in determining the supernova rate by means of historical records. Nevertheless, it again has no effect on a lower limit calculation.

The total number of supernovae in the galaxy, N_T, given by eq.(7) is an underestimated value due to that the contributions to N given by larger scale height and higher number density of massive stars (progenitors of supernovae) near the galactic center are neglected. Therefore, eq.(7) is also only available for a lower-limit calculation. For the same reason, we should take a smaller galactic radius, i.e. R = 12.5 Kpc.

The rate D is sensitive to the scale height of supernova, H_2. Considering the scale heights of both massive stars and SNR to be equal to about 60 pc, it is then reasonable to take H_2 = 60 pc. A recent result[7] showed, however, that the large-scale distribution of galactic radio supernova remnants essentially reflects the distribution of interstellar gas rather than that of the supernova progenitors. The gas component in the galactic disk possesses scale height of 200 pc. Therefore, we also calculated the rate D for H_2 = 250 pc.

It is quite difficult to tell the type of historical supernovae. AD1054 must be of type 2, because a pulsar lies in its remnant. AD1181 is also of type 2, because its SNR contains a similar nebular as the Crab. The two latest historical supernovae, i.e. supernova of Tycho and Kepler, have been identified as type 1. We know nothing about the type of the other four supernovae. Therefore, regarding the type, we only have two constraints $n_1 > 2$ and $n_2 > 2$. Because the observed ratio between the rates of type 1 and type 2 of supernova in external galaxies is about 1:10, it seems to be reasonable to take n = 2 and n = 6 in a lower limit estimation.

By using the above-mentioned selections on various parameters, one finds the rates D_1 and D_2 as

$$D_2 = 1/11 \ yr^{-1}, \ D_1 : D_2 = 1:5, \tag{8}$$

for H_2 = 60 pc;

$$D_2 = 1/20 \ yr^{-1}, \ D_1 : D_2 = 1:5, \tag{9}$$

for H_2 =250 pc.

4. From (8) and (9), a lower limit to the galactic stellar collapse rate can finally be set at > 1/20 yr^{-1}. This lower limit does not much differ from the rates given by heavy element content[3] and stellar formation[2], both of which require a rate of about 1/10 yr^{-1}. This is quite important. The rates of element content and stellar formation are found by an average over the whole lifetime of the galaxy, this is, the rates describe the average evolution of the galaxy. In contrast, the rate of (8) and (9) only relates to the past two thousand years, this is, it describes the present evolution of the galaxy. The absence of a large difference between the average rate and the present rate therefore implies that the variation and activity in galactic evolution may not be very strong.

A new catalog of historical supernovae, given by a recent identification of "guest stars" in ancient Chinese records, includes six new candidates of supernovae[6]. If all the new candidates are further confirmed as supernovae, the lower limit of (9) will becomes about 1/12 yr^{-1} . This result is more close than (9) to the rates of element content and stellar formation. Therefore, it would strengthen the conclusion about the lack of activity in galactic evolution. Furthermore, in this case, it would also imply that dim supernovae like 1987A may not be a dominant component of the stellar collapses in the galaxy.

References

1. A.Blair, in Experimental Gravitational Physics, eds. P.E.Michelson, E.K.Hu and G.Pizzella, World Scientific, 1988.

2. J.N.Bachall and T.Piran, Astrophys. J., 267, L77 (1983).

3. D.N.Schramm, Nucl. Phys. B (Proc. Suppl), 3, 471 (1988).

4. S.T.Dye, et al, Phys. Rev. Lett., 62, 2069 (1989).

5. D.H.Clark and F.R.Stepenson, Mon. Not. Roy. Adtr. Soc., 179, 87 (1977).

6. Q.B.Li, in High Energy Astrophysics, ed. G.Borner, Spring-Verlag, 1988.

7. S. van der Bergh, in Supernova 1987A in the Large Magellanic Cloud, eds. M.Kafatos and A.Michalitsianos Cambridge University Press, 1988.